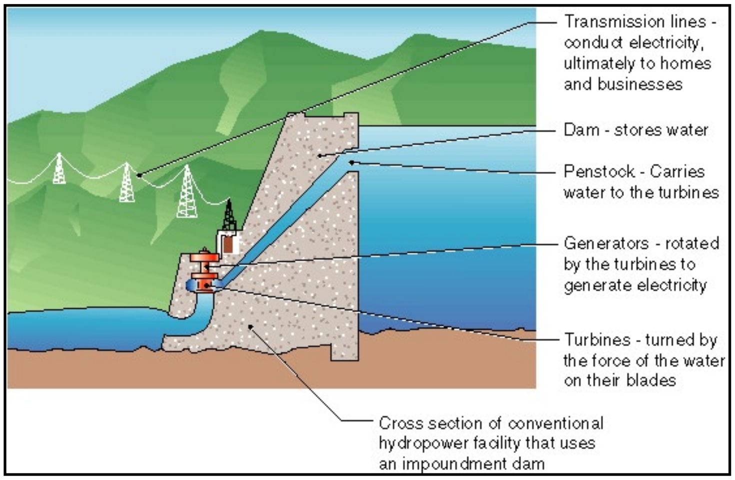
Advanced Hydropower

Technology Description

Advanced hydropower is new technology for producing hydroelectricity more efficiently, with improved environmental performance. Current technology often has adverse environmental effects, such as fish mortality and changes to downstream water quality and quantity. The goal of advanced hydropower technology is to maximize the use of water for hydroelectric generation while eliminating these adverse side effects—in many cases both increased energy and improved environmental conditions can be achieved.



System Concepts

- Conventional hydropower projects use either impulse or reaction turbines to convert kinetic energy in flowing or falling water into turbine torque and power. Source water may be from free-flowing rivers/streams/canals or released from upstream storage reservoirs.
- Improvements and efficiency measures can be made in dam structures, turbines, generators, substations, transmission lines, and systems operation that will help sustain hydropower's role as a clean, renewable energy source.

Representative Technologies

- Turbine designs that minimize entrainment mortality of fish during passage through the power plant.
- Autoventing turbines to increase dissolved oxygen in discharges downstream of dams.
- Reregulating and aerating weirs used to stabilize tailwater discharges and improve water quality.
- Adjustable-speed generators producing hydroelectricity over a wider range of heads and providing more uniform instream flow releases without sacrificing generation opportunities.
- New assessment methods to balance instream flow needs of fish with water for energy production.
- Advanced instrumentation and control systems that modify turbine operation to maximize environmental benefits and energy production.

Technology Applications

- Advanced hydropower products can be applied at more than 80% of existing hydropower projects (installed conventional capacity is now 78 GW); the potential market also includes 15–20 GW at existing dams without hydropower facilities (i.e., no new dams required for development) and about 30 GW at undeveloped sites that have been identified as suitable for new dams.
- The nation's largest hydropower plant is the 7,600 megawatt Grand Coulee power station on the Columbia River in Washington State. The plant is being upscaled to 10,080 megawatts, which will make it the third largest in the world.
- There would be significant environmental benefits from installing advanced hydropower technology, including enhancement of fish stocks, tailwater ecosystems, and recreational opportunities. These benefits would occur because the advanced technology reverses adverse effects of the past.
- Additional benefits would come from the protection of a wide range of ancillary benefits that are provided at hydropower projects but are at extreme risk of becoming lost in the new deregulated environment.

Current Status
• Hydropower (also called hydroelectric power) facilities in the United States can generate enough power to supply 28 million households with electricity, the equivalent of nearly 500 million barrels of oil. The total U.S. hydropower capacity—including pumped storage facilities—is about 95,000 megawatts. Researchers are working on advanced turbine technologies that will not only help maximize the use of hydropower but also minimize adverse environmental effects. • According to EIA, hydropower provided 12.6% of the nation's electricity generating capability in 1999 and 80% of the electricity produced from renewable energy sources. • DOE estimates current capital costs for large hydropower plants to be $1,700 to $2,300 per kW (although no new plants are currently being built in the United States and O&M is estimated at approximately 0.7 cents/kWh). • Worldwide, hydropower plants have a combined capacity of 675,000 megawatts and annually produce more than 2.3 trillion kilowatt-hours of electricity, the energy equivalent of 3.6 billion barrels of oil. • Existing hydropower generation is declining because of a combination of real and perceived environmental problems, regulatory pressures, and changes in energy economics (deregulation, etc.); potential hydropower resources are not being developed for similar reasons. • The current trend is to replace hydropower with electricity from fossil fuels. • Some new, environmentally friendly technologies are being implemented (e.g., National Hydropower Association's awards for Outstanding Stewardship of America's Rivers). • DOE's Advanced Hydropower Turbine System (AHTS) program constructed a test facility to pilot test a new turbine design to evaluate hydraulic and biological performance; testing at this facility was completed in 2003. This program is demonstrating that new turbine designs are feasible, but additional support is needed to fully evaluate these new designs in full-scale applications. • There is insufficient understanding of how fish respond to turbulent flows in draft tubes and tailraces to support biological design criteria for those zones of power plants. • Fish resource management agencies do not recognize that the route through turbines is acceptable for fish—this perception could be overcome if field-testing continues to show mortality through turbines is not greater than other passage routes. • TVA's Lake Improvement Plan has demonstrated that improved turbine designs can be implemented with significant economic and environmental benefits. This effort has shown increases in hydroelectric plants' energy production by 12% with significantly improvements of downstream fish resources. • Field-testing of the Minimum Gap Runner (MGR) designs for Kaplan turbines indicate that fish survival up to 98% is possible, if conventional turbines are modified. • FERC instituted a short-term reduction in regulatory barriers on the West Coast in 2001—this resulted in more than 100,000 MWh of additional generation and a significant shift from nonpeak to peak production, without significant adverse environmental effects. • Regulatory trends in relicensing are to shift operation from peaking to baseload, effectively reducing the energy value of hydroelectricity; higher instream flow requirements are also reducing total energy production to protect downstream ecosystems, but scientific justification is weak. • Frequent calls for dam removal is making relicensing more costly to dam owners. • Regional efforts by Army Corps of Engineers and Bonneville Power Administration are producing some site-specific new understanding, especially in the Columbia River basin; but commercial applications are unlikely because of pressures from industry deregulation and environmental regulation. • Voith-Siemans Hydro and TVA have established a limited partnership to market environmentally friendly technology at hydropower facilities. Their products were developed in part by funding provided by DOE and the Corps of Engineers, as well as private sources. • Flash Technology is developing strobe lighting systems to force fish away from hydropower intakes and to avoid entrainment mortality in turbines.

Technology History
• Since the time of ancient Egypt, people have used the energy in flowing water to operate machinery and grind grain and corn. However, hydropower had a greater influence on people's lives during the 20th century than at any other time in history. Hydropower played a major role in making the wonders of electricity a part of everyday life and helped spur industrial development. Hydropower continues to produce 24% of the world's electricity and supply more than 1 billion people with power. • The first hydroelectric power plant was built in 1882 in Appleton, Wisconsin, to provide 12.5 kilowatts to light two paper mills and a home. Today's hydropower plants generally range in size from several hundred kilowatts to several hundred megawatts, but a few mammoth plants have capacities up to 10,000 megawatts and supply electricity to millions of people. • By 1920, 25% of electrical generation in the United States was from hydropower; and, by 1940, was 40%. • Most hydropower plants are built through federal or local agencies as part of a multipurpose project. In addition to generating electricity, dams and reservoirs provide flood control, water supply, irrigation, transportation, recreation, and refuges for fish and birds. Private utilities also build hydropower plants, although not as many as government agencies.
Technology Future
• By 2003, a quantitative understanding of the responses of fish to multiple stresses inside a turbine should be developed. Biological performance criteria for use in advanced turbine design also should be available. • By 2005, environmental mitigation studies should be available on topics such as in-stream flow needs to produce more efficient and less controversial regulatory compliance. In addition, pilot-scale testing of new runner designs, including field evaluation of environmental performance, will allow full-scale prototype construction and testing to proceed. • By 2010, full-scale prototype testing of AHTS designs should be completed, including verified biological performance of AHTS in the field. This will allow AHTS technology to be transferred to the market.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003.

Hydroelectric Power

Market Data

U.S. Installed Capacity (MW)*	Source: Renewable Energy Project Information System (REPiS), Version 7, NREL, 2003.											
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Annual	1,391	3,237	862	1,054	19.9	64.0	7.6	179.3	1.1	11	0.002	21.0
Cumulative	80,491	87,839	90,955	94,052	94,072	94,136	94,143	94,323	94,324	94,335	94,335	94,356

* There are an additional 21 MW of hydroelectric capacity that are not accounted for here because they have no specific online date.
2003 data not complete as REPiS database is updated through 2002.

Cumulative Grid-Connected Hydro Capacity (MW)[1]	Source: U.S. data from EIA, AER 2003 Table 8.11a, World Total from EIA, International Energy Annual, 1996-2003, Table 6.4. International data from International Energy Agency, Electricity Information 2004.											
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S.												
Conventional and other Hydro	81,700	88,900	73,923	78,562	76,437	79,415	79,151	79,393	79,359	79,484	79,354	79,366
Pumped Storage[2]	N/A	N/A	19,462	21,387	21,110	19,310	19,518	19,565	19,522	19,096	20,373	20,373
U.S. Hydro Total	81,700	88,900	93,385	99,948	97,548	98,725	98,669	98,958	98,881	98,580	99,727	99,739
OECD Europe[3]	124,184	124,577	130,886	132,893	134,902	135,939	133,307	136,251	140,779	141,913	147,580	NA
IEA Europe[4]	123,960	124,357	130,663	132,666	134,038	135,074	132,315	135,254	138,093	138,912	144,010	NA
Japan	21,377	19,980	20,825	21,171	21,222	21,277	21,477	21,555	22,019	22,081	21,690	NA
OECD Total	286,969	300,725	316,291	340,259	342,893	346,342	342,673	346,446	351,513	352,564	338,130	NA
IEA Total	286,745	300,505	316,068	330,703	331,947	335,395	331,930	335,768	339,145	339,880	324,920	NA
World Total	470,669	537,734	600,206	650,936	661,237	673,797	680,610	697,749	712,689	723,581	NA	NA

1. Excludes pumped storage, except for specific U.S. pumped storage capacity listed.

2. Pumped storage values for 1980-1985 are included in "Conventional and other Hydro"
3. OECD included 24 countries as of 1980. Mexico, Czech Republic, Hungary, Poland, South Korea, Slovak Republic joined after 1980. Countries' data are included only after the year they joined.

4. IEA included 26 countries as of 2003. Countries' data are included only after the year they joined the OECD.
NA = Not Available; Updated international data not available at time of publication

Annual Generation from Cumulative Installed Capacity (Billion kWh)	Source: EIA, *International Energy Annual 2002*, DOE/EIA-0219(02), Table 1.5.										
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
United States	279	284	289	308	344	352	319	313	270	208	255
Canada	251	301	294	332	352	347	329	342	355	330	315
Mexico	17	26	23	27	31	26	24	32	33	28	25
Brazil	128	177	205	251	263	276	289	290	302	265	282
Western Europe	432	453	453	506	491	506	523	531	555	553	503
Former U.S.S.R.	184	205	231	238	215	216	225	227	228	239	243
Eastern Europe	27	26	23	34	34	36	35	35	31	30	32
China	58	91	125	184	185	193	203	211	241	258	309
Japan	88	82	88	81	80	89	92	86	86	83	81
Rest of World	273	328	435	504	515	522	533	541	558	571	581
World Total	1,736	1,973	2,167	2,466	2,511	2,564	2,571	2,609	2,658	2,565	2,627

State Generating Capability* (MW)	Source: EIA, Electric Power Annual 2002 – Spreadsheets, "1990 - 2002 Existing Nameplate and Net Summer Capacity by Energy Source and Producer Type (EIA-860)" http://www.eia.doe.gov/cneaf/electricity/epa/existing_capacity_state.xls										
Top 10 States	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Washington			19,935	20,487	20,431	20,923	21,012	21,011	21,011	21,006	21,016
California			12,687	13,519	13,500	13,475	13,383	13,445	13,475	13,471	13,523
Oregon			8,221	8,268	8,267	8,264	8,265	8,249	8,261	8,240	8,211
New York			5,345	5,545	5,557	5,565	5,668	5,662	5,659	5,712	5,804
Tennessee			3,717	3,818	3,818	3,937	3,950	3,950	3,950	3,948	3,948
Georgia			2,453	3,287	3,005	3,305	3,314	3,314	3,313	3,313	3,613
South Carolina			2,367	3,468	3,468	3,442	3,442	3,452	3,455	3,453	3,453
Virginia			3,072	3,126	3,149	3,082	3,093	3,090	3,091	3,088	3,088

Alabama	2,857	2,868	2,864	2,904	2,961	2,961	2,961	2,959	2,959
Arizona	2,685	2,885	2,885	2,893	2,893	2,890	2,890	2,890	2,893
U.S. Total	89,828	94,513	94,372	95,222	95,496	95,802	95,879	95,844	96,343

* Values are nameplate capacity for total electric industry

State Annual Generation from Cumulative Installed Capacity* (Billion kWh)	Source: EIA, Electric Power Annual 2002 – Spreadsheets, “1990 - 2002 Net Generation by State by Type of Producer by Energy Source (EIA-906)” http://www.eia.doe.gov/cneaf/electricity/epa/generation_state.xls										
Top 10 States	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Washington			87.5	82.5	98.5	104.2	79.8	97.0	80.3	54.7	78.2
Oregon			41.2	40.8	44.9	46.7	39.9	45.6	38.1	28.6	34.4
California			24.8	50.5	46.9	42.1	50.8	40.4	39.3	25.2	30.9
New York			27.1	24.8	27.8	29.5	28.2	23.6	23.9	22.2	24.1
Montana			10.7	10.7	13.8	13.4	11.1	13.8	9.6	6.6	9.6
Alabama			10.4	9.5	11.1	11.5	10.6	7.8	5.8	8.4	8.8
Idaho			9.1	11.0	13.3	14.7	12.9	13.5	11.0	7.2	8.8
Arizona			7.7	8.5	9.5	12.4	11.2	10.1	8.6	7.9	7.6
Tennessee			9.5	9.0	10.8	10.4	10.2	7.2	5.7	6.2	7.3
South Dakota			3.9	6.0	8.0	9.0	5.8	6.7	5.7	3.4	4.4
U.S. Total			289.4	308.1	344.1	352.4	318.9	313.4	270.0	208.1	255.6

* Values are for total electric industry. Years before 1998 do not include nonutility generation.

Annual Hydroelectric Consumption for Electric Generation (Trillion Btu)	Source: *EIA, Annual Energy Review 2003, DOE/EIA-0384(2003) (Washington, D.C., September 2004) Table 8.4a*											
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S. Total	2,900	2,970	3,046	3,205	3,590	3,640	3,297	3,268	2,811	2,201	2,675	2,779
Note: Conventional hydroelectric power only, for all sectors.												
Hydroelectric data through 1988 include industrial plants as well as electric utilities. Beginning in 1989, data are for electric utilities, independent power producers, commercial plants, and industrial plants.												